STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

CARBON MONOXIDE CONCENTRATIONS ADJACENT TO SOUND BARRIERS

Study Supervised by .... Mas Hatano, P.E.

Principal Investigators .... Roy Bushey, P.E.
Paul E. Benson, P.E.

Co-Principal Investigators .... Bennett Squires, P.E.
& William A. Nokes, P.E.

Report Prepared by .... William A. Nokes, P.E.
& Paul E. Benson, P.E.

RAYMOND A. FORSYTH, P.E.
Chief, Office of Transportation Laboratory

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16. ABSTRACT

The effects of a sound wall on air pollutant dispersion at a selected freeway section are discussed. Carbon monoxide levels within the sound wall section are compared to concentrations observed at a nearby site without a sound wall. It is suggested that the differences in carbon monoxide levels between the two sites are caused by confinement and increased residence time of pollutants in the roadway mixing zone. Carbon monoxide concentrations in a subdivision adjoining the sound wall section are compared to pollutant levels within the section. Ranges of carbon monoxide levels at sites located at various distance from the lee side of the wall are presented. Aerodynamic uplift of the pollutants flowing from the mixing zone over the sound wall is described. The sound wall is shown to increase carbon monoxide levels within the freeway mixing zone by trapping emissions. This increase is reported to be offset by increased initial vertical dispersion of emissions and lifting of the air flow over the sound wall.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

In recent years the California Department of Transportation (Caltrans) has responded to public concerns about noise pollution from roadway corridors by constructing sound walls (also referred to as sound barriers and noise barriers) in many locations. These barriers are built to limit traffic noise from infringing on adjoining residence and public facilities. They have proven effective in achieving significant noise reductions in many problem areas.

Concern about one aspect of sound walls has appeared frequently in public comments. Many people feel that sound walls constrict air circulation near roadways, thereby decreasing the flow of fresh air and increasing air pollutant concentrations.

In response to these concerns, the Transportation Laboratory (TransLab) conducted a field experiment to investigate the distribution of vehicular air pollutants near sound walls. The test site was located in Sacramento on the south side of U.S. Route 50 adjacent to a new residential subdivision (see Figure 1). Concentration measurement of the relatively inert pollutant, carbon monoxide (CO), was used as the basis for characterizing pollutant dispersion in and near the freeway sound wall.

BACKGROUND

Roadways bounded by sound walls and depressed roadway sections are similar in terms of their potential for confining vehicular emissions. Data from previous field studies by Caltrans revealed dispersion patterns near depressed

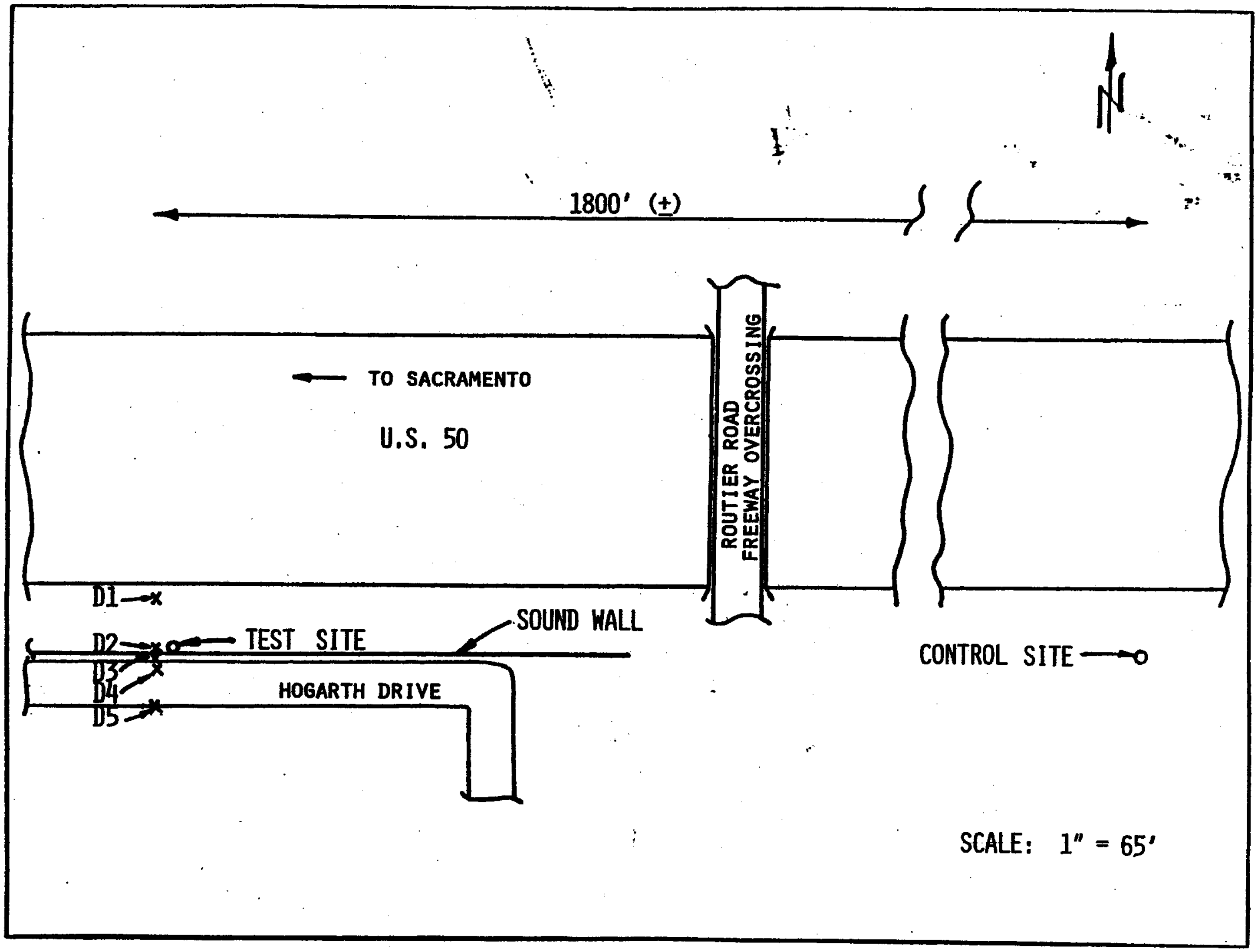

FIGURE 1. Freeway Test Section Site Plan

sections that were incorporated into a nationally recognized dispersion model(1,2,3). These studies showed lower concentrations downwind from a depressed section when compared to equivalent at-grade and elevated sites. The reduced downwind pollutant concentrations were attributed to more extensive initial vertical disperson caused by longer pollutant residence time in the intensely turbulent roadway mixing zone region (the area above the traveled way is described as the mixing zone - see Figure 2). This enhanced vertical dispersion and decreased rate of pollutant transport out of the mixing zone (caused by channeling and eddying) is expected to be similar for freeway sections bounded by sound walls.

Changes in flow caused by obstructions which are similar to sound walls have been studied by others(4-7). Figure 2 depicts a uniform flow field across a sharp-edged plate(5, 7). Streamlines compress over the top edge as a separated wake develops on the lee side of the wall. Within in this wake a cavity region develops below the separation streamline. Undisturbed flow is reestablished further downwind as residual effects of the obstacle diminish.

The point of separation of flow for a sharp-edged obstacle occurs at the edge of the obstacle under all atmospheric stability conditions(7). The size and extent of the cavity region is restricted by stable atmospheric conditions. The largest cavity region occurs for an isolated and impervious obstacle with a vertical face(5,7) such as a sound wall.

Figure 2 represents an idealized situation. Wind tunnel studies usually assume that windward flow toward an obstacle is laminar, i.e., undisturbed(4,5,7). This condition contrasts with the vehicle-induced turbulence present in a

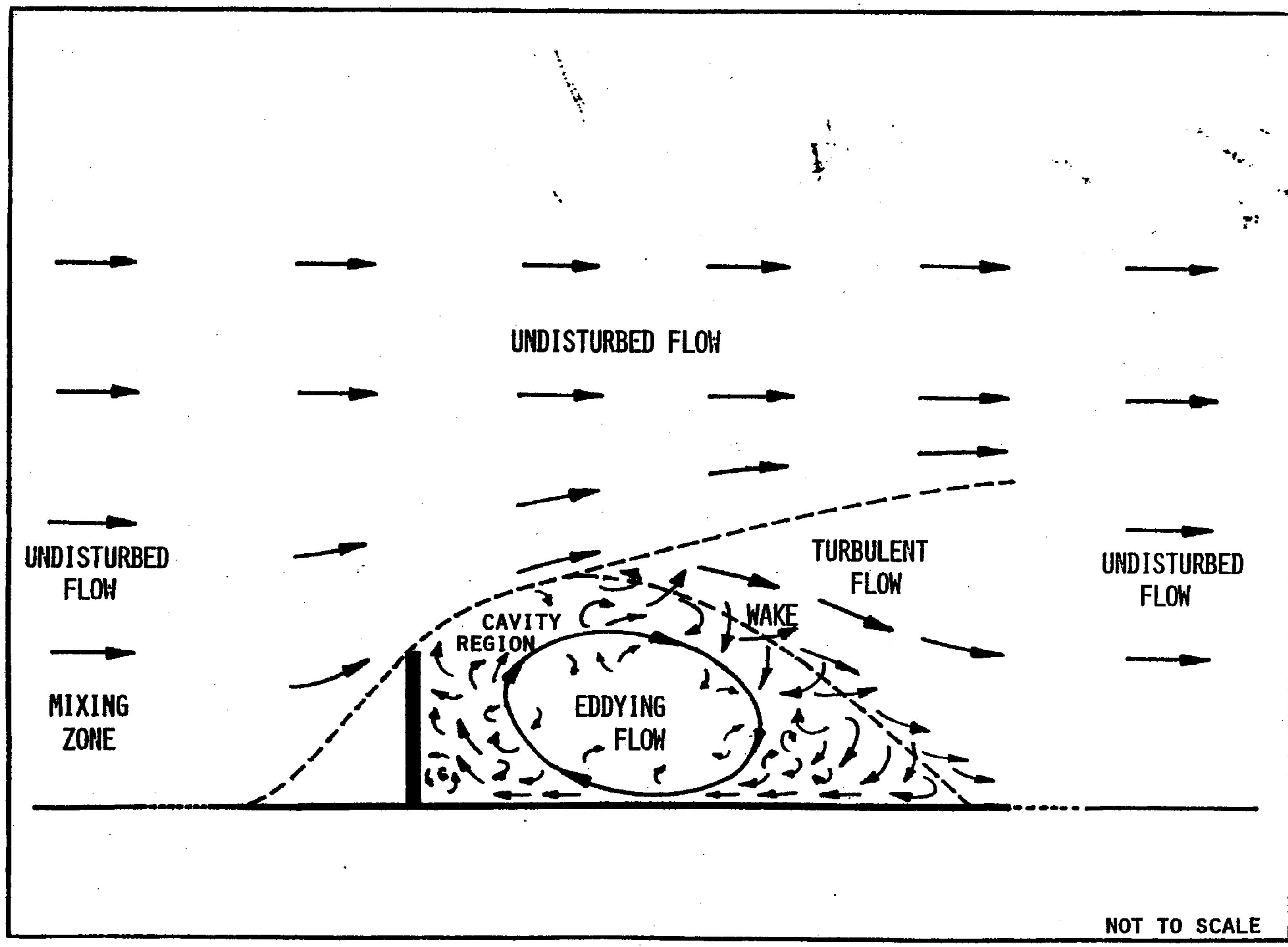

FIGURE 2. Flow Profile Across a Sharp-Edged Plate

freeway mixing zone. Puttock and Hunt report that any error caused by assuming laminar flow should be small because diffusion in a flow straining across an obstruction is dominated by advection and the convergence and divergence of streamlines(6).

In urban settings wind flow is typically interrupted by many other types of obstructions. Rapid velocity changes and uplift of the flow streamlines are similar for obstacle shapes such as quarter-circle cross-sections, sharp-edged plates, and screen fences(4). Predicting characteristics of the flow field between the obstacle and the reattachment point for a specific obstacle requires knowledge of the boundary layer velocity distribution and the type of obstacle. Such predictions were not attempted in this study. Instead, measured concentrations were examined for consistency with the above theories.

DESCRIPTION OF WORK

The freeway section where the data were collected is part of a main transportation artery in the east Sacramento area. It carries an ADT of 80,000 vehicles with a peak hour of about 9,000 vehicles. The freeway geometry does not change significantly between the test and control sites. The sound wall is approximately 8 feet high and constructed of corrugated metal with a thickness of less than 0.5 inch.

The field experiment consisted of two separate sampling strategies. The first was a monitoring network of five sampling sites located on a line perpendicular to the freeway. Data were collected from late April to the end of May. Figure 1 shows that two sites were located on the freeway side of the wall and three sites were in the subdivision. Two separate sampling tubes conveyed air samples from each site back to two, independent NDIR CO analyzers. Air samples were drawn sequentially from each site at one minute intervals. This approach provided hourly averaged point concentrations on both side of the sound barrier. These measurements were recorded on magnetic tape for later transfer to Caltrans' computerized Air Quality Data Handling System.

The second monitoring strategy, conducted from mid-May to early June, consisted of one test site on the freeway side of the wall and one control site located approximately onethird of a mile east at a location where no sound wall was present. Hourly air samples were drawn into Tedlar bags and then analyzed at TransLab for CO concentrations.

DATA ANALYSIS

Results from the field sampling revealed two important facts:

1) CO concentrations observed in the sound wall mixing zone were typically higher than at the control site.

2) CO levels were dramatically lower on the subdivision side of the wall than coincidental concentrations on the freeway side of the wall.

Evaluation of the CO levels at the test and control sites focused on determining if the higher CO levels in the sound wall-mixing zone region were statistically significant. Similarly, analysis of CO levels at sites D1 through D5 sought to evaluate and explain the consistently lower CO values observed at all sites on the subdivision side of the wall.

A frequency histogram and cumulative frequency plot of CO concentrations from the test section and control sites are shown in Figures 3 and 4, respectively. Carbon monoxide levels at these two sampling sites were compared to find out if the higher levels at the sound wall site were significant. Two different test methods were used. The first method, the Student's t-test assumes that the parent population of CO concentrations follows a normal distribution. The t-test for paired data was appropriate in this instance because concurrent measurements were drawn from two locations which were subjected to different conditions. The test results showed that the difference between the CO levels at the test and control sites was significant at the 99% confidence level (two-tailed). Thus, while vehicle emissions and meteorology were approximately equivalent at the two sites, CO concentrations within the freeway mixing zone were significantly higher with the sound wall present.

The second statistical test is called the Wilcoxon Matched-Pairs Signed-Ranks test. This test was used because it does not require any assumptions about the frequency distribution of the parent population. The two-tailed Wilcoxon test again showed that the difference in CO concentrations between the control and the test sites was significant at the 99% confidence interval.

The data collected in this experiment support the hypothesis that CO levels in the freeway mixing zone are higher with a sound wall present. This elevated CO concentration can probably be attributed to the confining influence of the wall and consequent increase in pollutant residence time within the mixing zone.

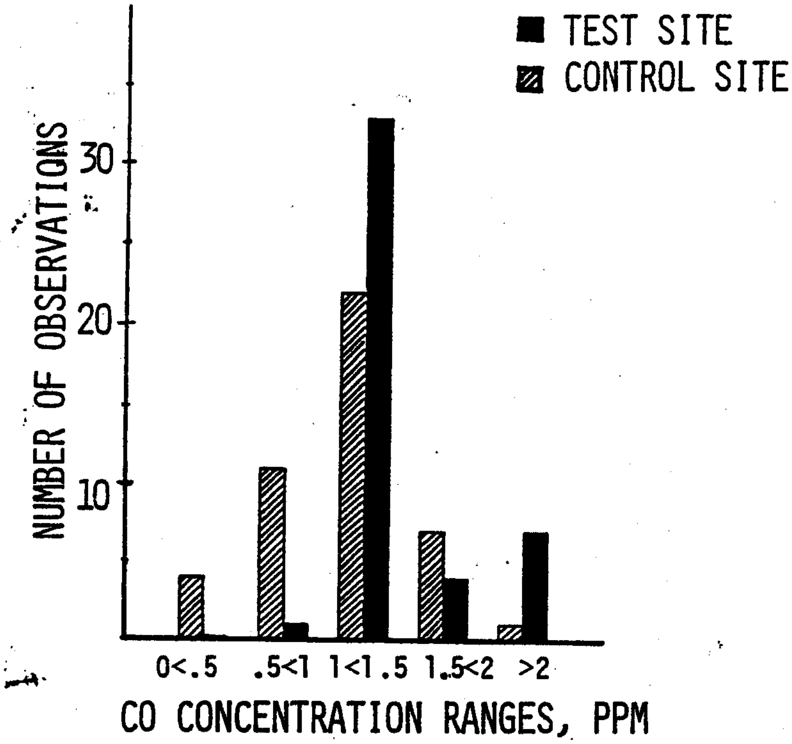

FIGURE 3. DISTRIBUTION OF CO CONCENTRATIONS AT TEST AND CONTROL SITES.

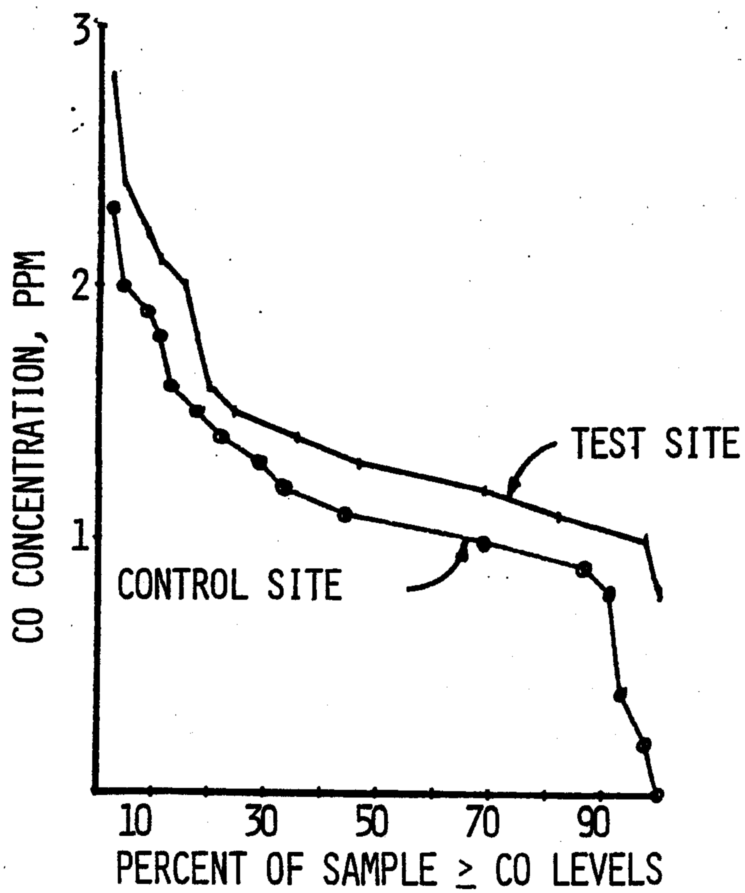

FIGURE 4. CUMULATIVE FREQUENCY CO DISTRIBUTIONS AT TEST & CONTROL SITES.

Earlier discussion of the comparison between depressed sections and sound wall corridors mentioned the likelihood of enhanced initial vertical dispersion occurring as a result of vehicle-induced turbulence and increased pollutant residence time in the mixing zone. The combined effect of these factors should cause a net reduction in pollutant levels at the sites beyond the sound barrier. Figure 5 shows the ranges of all CO concentrations recorded for each monitoring site. It is apparent that CO concentrations are dramatically lower on the residential side of the sound wall. The wall is located between sites D2 and D3 and these sites are only six feet apart, yet there is almost a 20% reduction in maximum CO levels. This reduction is likely caused by the enhanced initial vertical dispersion and the aerodynamic uplift provided by the wall.

The range of CO concentrations on the subdivision side of the wall shown in Figure 5 is extremely consistent. This indicates an approximately homogeneous distribution of CO within the cavity region downwind of the wall.

Puttock and Hunt analyzed the diffusion of emissions from a line source located near a generalized two-dimensional obstacle(6). The flow field was assumed to be uniform and perpendicular to the major axis of the obstruction. They also assumed an approximately uniform concentration within the wake. This uniformity was expected for two reasons: (1) a high level of turbulence within the wake would promote efficient mixing, and (2) rapid advection of pollutants in the outer flow would lead to little change in concentration from the point of separation to the point of reattachment.

The ranges of concentration at sites D3, D4, and D5, shown in Figure 5, indicates fairly constant CO levels in the

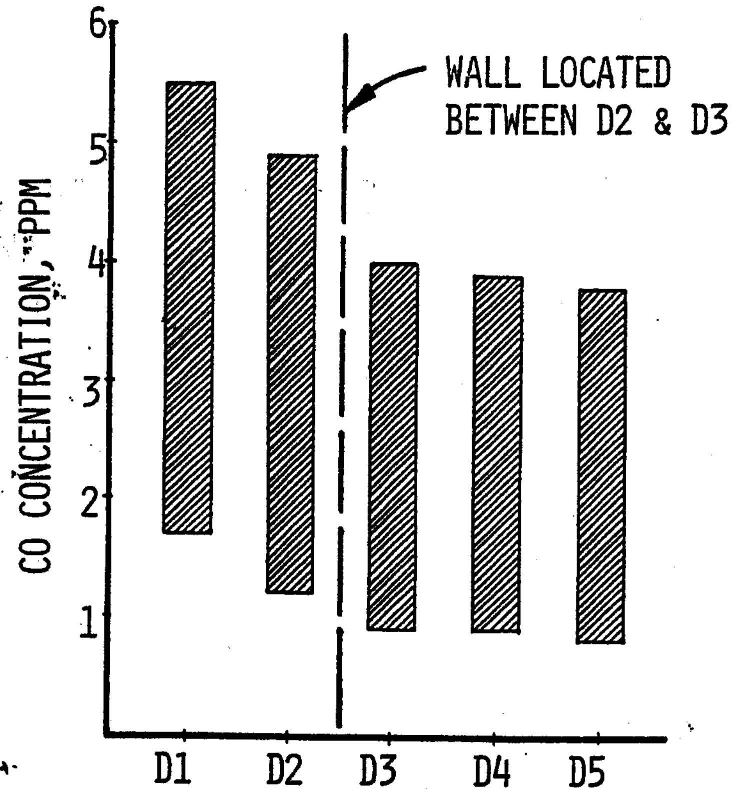

FIGURE 5. RANGE OF CO CONCENTRATIONS DISTRIBUTED BY SAMPLING SITE.

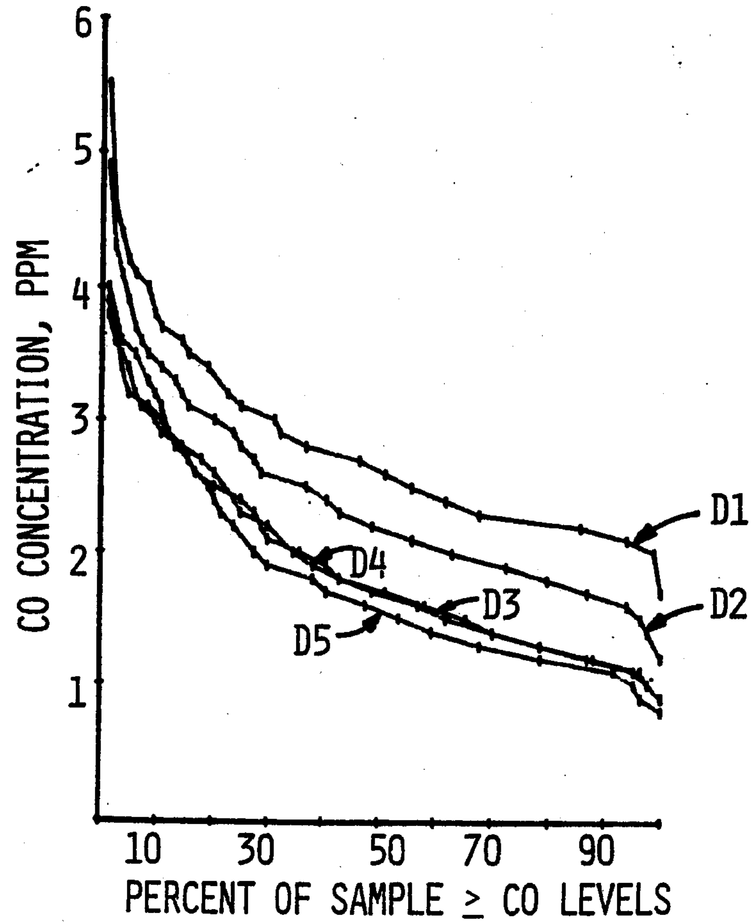

FIGURE 6. CUMULATIVE FREQUENCY DISTRIBUTIONS OF CO BY SAMPLING SITE.

wake. Since similar ranges of CO were observed at each site, it appears that these sites were all located within the wake.

Though the distance to the reattachment is difficult to determine, it should range in length from 10 to 30 times the height of the wall depending on site and flow conditions(5). Since the plate-like shape of a sound wall causes a large cavity region, site D5 is probably located well within this region.

Figure 6 shows cumulative frequency distributions of CO levels recorded at respective sites. The cumulative frequency plot contrasts the distribution of CO levels for each site over the entire range of values encountered. Figure 6 indicates that the dramatic drop in CO concentrations across the wall is constant over the full range of CO values observed. Figure 6 also repeats the flat dispersion pattern shown in Figure 5 at sites D3, D4, and D5. The homogeneity of CO levels at these sites is consistent over the entire range of observed values.

It is apparent that concentrations are significantly reduced on the residential side of the wall. This reduction typically amounts to about 20% (for concentrations above 2 ppm). Conversely, mixing zone concentrations are apparently increased by the presence of sound walls. This increase averages slightly less than 20%. It appears then that the increase in CO concentrations within the freeway mixing zone is offset by the reduced CO levels downwind of the wall.

CONCLUSIONS

The CO concentration distributions observed near a section of freeway bounded by a sound wall were similar to distributions measured near a depressed freeway section previously studied. It has been argued that the same physical mechanisms of pollutant confinement and higher initial vertical dispersion are acting at both types of sites. The observations analyzed in this report indicate that sound walls act to increase pollutant residence time in the mixing zone leading to approximately 20% higher CO concentrations on the freeway side of the walls. Offsetting this effect is the increased initial vertical dispersion of vehicle emissions due to the longer residence time in the intensely turbulent mixing zone, and the uplift effect of the wall itself. Based on the combined results of these effects, it is concluded that no significant net change in CO concentrations at residential receptors and public facilities can be attributed to the presence of a sound wall.

IMPLEMENTATION

It is recommended that this report be distributed as an informational document to members of the public who have expressed a concern over possible air quality impacts of sound barriers. It is important to remember that the conclusions were based on limited data taken at a single site. However, these results agreed favorably with published theories.

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